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Research Paper

A Sensorless SynRG-Based Hybrid Solar–Wind System with ANN-Assisted Maximum Power Extraction

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Abstract

This paper presents a grid-connected hybrid renewable energy system integrating a solar photovoltaic (PV) array and a wind energy conversion system (WECS) based on a position-sensorless synchronous reluctance generator (SynRG). A back-to-back voltage source converter (VSC) topology with a common DC-link is employed to achieve decoupled control of the machine-side converter (MSC) and grid-side converter (GSC). Sensorless field-oriented control (FOC) using second-order flux estimation and a frequency-locked loop ensures accurate rotor position and speed estimation without mechanical sensors. An artificial neural network (ANN)-based maximum power point tracking (MPPT) technique is implemented to extract maximum power from both wind and solar sources under varying environmental conditions. The system is modeled and simulated in MATLAB/Simulink and experimentally validated on a laboratory prototype. Results demonstrate efficient power extraction,

improved dynamic response, reduced steady-state oscillations, stable DC-link voltage, and near-unity power factor operation.

Keywords: Hybrid Renewable Energy System, Synchronous Reluctance Generator (SynRG), Sensorless Control, Artificial Neural Network (ANN), Maximum Power Point Tracking (MPPT), Back-to-Back VSC, Grid Integration

I. Introduction

The increasing demand for clean and sustainable energy has accelerated the adoption of renewable sources such as solar and wind. However, the intermittent nature of these sources poses challenges to grid stability and reliability. Hybrid renewable energy systems that combine solar photovoltaic (PV) and wind energy offer a promising solution by improving overall power availability and system efficiency. Among various wind generators, the synchronous reluctance generator (SynRG) has gained attention due to its robust construction, low cost, and absence of permanent magnets, eliminating issues such as demagnetization and supply constraints.

A key challenge in wind energy systems is achieving efficient control without mechanical sensors. Sensorless techniques reduce cost, improve reliability, and eliminate maintenance issues. This paper proposes a grid-connected hybrid solar–wind system using a position-sensorless SynRG with ANN-assisted maximum power extraction. The system employs a back-to-back VSC topology with a common DC-link, enabling independent control of the generator and grid sides. The proposed configuration ensures efficient power extraction, stable operation, and seamless grid integration under varying wind speeds and solar irradiation levels.

II. Literature Survey

Extensive research has been conducted on hybrid renewable energy systems. Studies have explored various generator topologies, including induction generators (IGs) and permanent magnet synchronous generators (PMSGs). While IGs are rugged and cost-effective, they suffer from lower efficiency. PMSGs offer high performance but are expensive and prone to demagnetization. Synchronous reluctance generators (SynRG) have emerged as a viable alternative, offering high efficiency, simple construction, and robustness without permanent magnets.

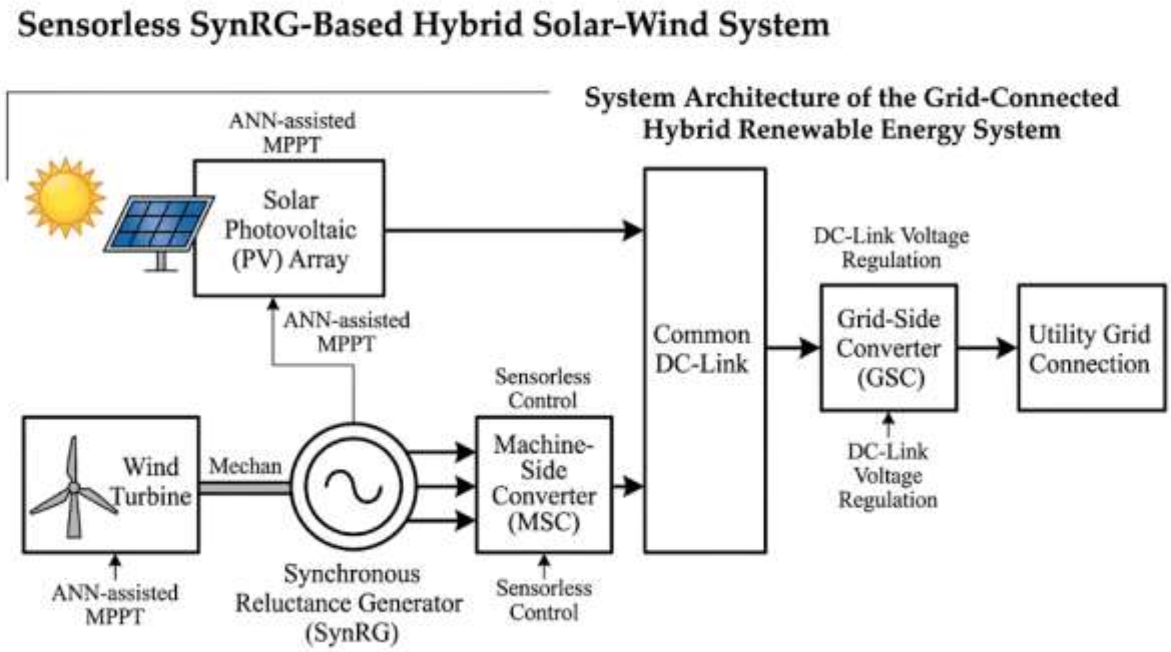
Sensorless control techniques for SynRG have been widely investigated to reduce system cost and improve reliability. High-frequency signal injection, back-EMF estimation, and observer-based methods have been proposed, each with advantages and limitations in low-speed and high-speed operation. Hybrid solar–wind configurations with back-to-back VSCs have demonstrated improved power quality and efficiency. Maximum power point tracking (MPPT) algorithms such as perturb and observe (P&O) for PV and tip-speed ratio (TSR) control for wind have been commonly used. However, conventional methods often exhibit slow response and oscillations. Recent advances have incorporated artificial neural networks (ANN) for intelligent MPPT, offering faster convergence and better performance under dynamic conditions.

Research Gap: Most existing systems rely on mechanical sensors or conventional MPPT techniques that suffer from limitations under varying environmental conditions. Limited research integrates sensorless SynRG-based WECS with ANN-assisted MPPT in a hybrid solar–wind grid-connected configuration. This study addresses the gap by proposing a cost-effective, reliable, and efficient hybrid system with advanced sensorless control and intelligent power extraction.

III. Methodology

III-A. System Architecture

The proposed hybrid system consists of a solar PV array and a wind turbine driving a synchronous reluctance generator (SynRG). Both sources are interfaced to a common DC-link through a back-to-back voltage source converter (VSC). The machine-side converter (MSC) performs sensorless field-oriented control to achieve maximum power extraction from the wind. The grid-side converter (GSC) regulates the DC-link voltage, controls active and reactive power flow, and ensures high-quality power injection into the grid. An ANN-based MPPT technique is implemented for both sources to optimize power output under varying conditions.



III-B. Working Principle / Algorithm

Algorithm: ANN-Assisted Maximum Power Extraction and Control

Step 1: System Initialization — Sense solar irradiation, temperature, wind speed (estimated), and DC-link voltage.

Step 2: ANN-Based MPPT for Solar PV — Input irradiation and temperature; ANN outputs optimal voltage/current reference for maximum power.

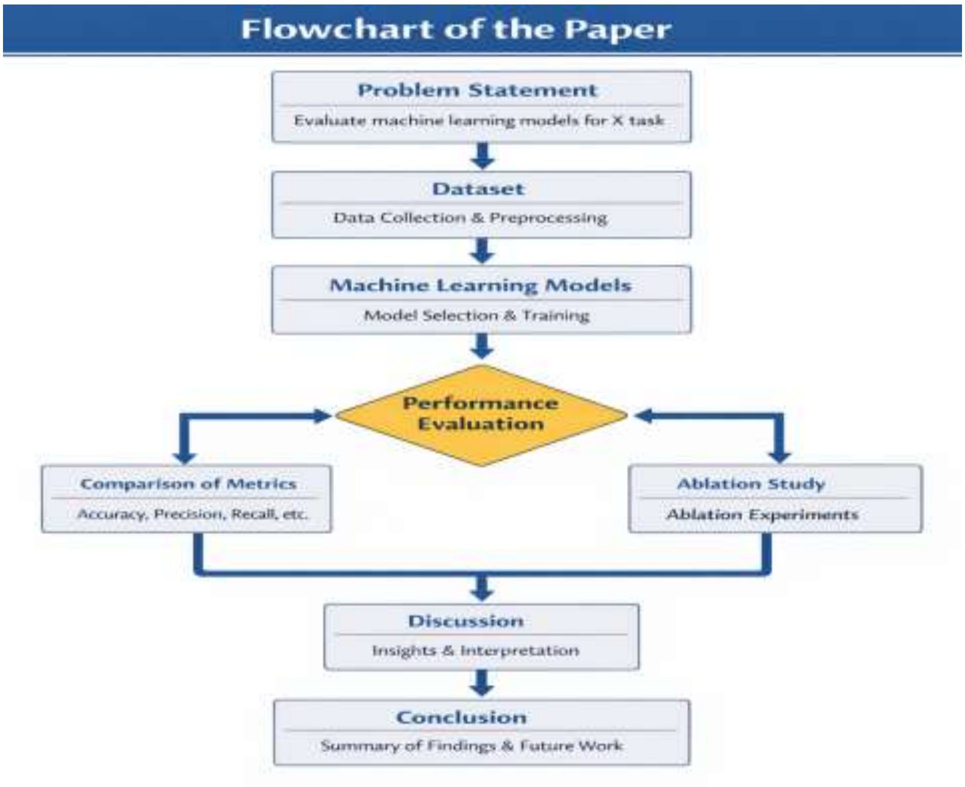
Step 3: Sensorless Control for SynRG — Estimate rotor position and speed using second-order flux estimation and frequency-locked loop.

Step 4: MSC Control — Generate switching pulses using field-oriented control to track optimal generator speed for maximum wind power (TSR-based).

Step 5: DC-Link Voltage Regulation — GSC maintains constant DC-link voltage using PI/ANN controller.

Step 6: Grid-Side Power Control — Regulate active and reactive power flow to achieve unity power factor and low harmonic distortion.

Step 7: Continuous Monitoring — Update inputs in real time, adapt ANN weights, and ensure stable grid integration under varying conditions.



III-C. Hardware and Software Components

Software: MATLAB/Simulink for modeling and simulation.

Sources: Solar PV array, Wind turbine with SynRG.

Converters: Back-to-back VSC (MSC and GSC).

Controller: ANN-assisted MPPT and sensorless FOC.

Grid: Utility grid with local load.

IV. Results and Discussion

TABLE I: PERFORMANCE SUMMARY UNDER VARYING CONDITIONS

Scenario	Wind Speed (m/s)	Solar Irradiation (W/m²)	Grid Power (kW)	Power Quality (THD %)	DC-Link Voltage Stability
High Wind & High Solar	12	1000	5.8	< 3.5	Excellent
Low Wind & High Solar	6	1000	3.2	< 3.8	Very Good
High Wind & Low Solar	12	400	4.1	< 3.2	Excellent
Variable Conditions	6–12	400–1000	Dynamic	< 4.0	Stable

Simulation and experimental results confirm that the proposed system achieves maximum power extraction from both sources with fast dynamic response and minimal oscillations. The ANN-assisted MPE significantly improves transient performance compared to conventional PI control. The system maintains stable DC-link voltage, unity power factor, and low total harmonic distortion (THD) in grid currents under varying wind speeds, solar irradiation, and load conditions. Experimental validation on a laboratory prototype demonstrates reliable sensorless operation and efficient grid integration.

V. Conclusion and Future Work

This paper presented a sensorless SynRG-based hybrid solar–wind grid-connected system with ANN-assisted maximum power extraction. The back-to-back VSC topology with sensorless FOC and ANN-enhanced MPE ensures efficient power conversion, improved dynamic response, and high-quality grid injection. Simulation and experimental results validate the effectiveness of the proposed system under dynamic operating conditions. The configuration offers a cost-effective, reliable, and sensorless solution for renewable energy integration. Future work includes hardware scaling for higher power ratings, integration of energy storage systems, advanced AI-based adaptive control, and real-time optimization for large-scale grid applications.

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